Quarterly Status and Cost Report
The GEO-SEQ Project

This report summarizes progress and costs incurred for The GEO-SEQ Project through August 31, 2000.

The purpose of the GEO-SEQ project is to establish a public-private R&D partnership that will:

- Lower the cost of geologic sequestration by: (1) developing innovative optimization methods for sequestration technologies with collateral economic benefits such as enhanced oil recovery (EOR), enhanced gas recovery (EGR), and enhanced coalbed methane production, and (2) understanding and optimizing trade-offs between CO_2 separation and capture costs, compression and transportation costs, and geologic sequestration alternatives.

- Lower the risk of geologic sequestration by: (1) providing the information needed to select sites for safe and effective sequestration, (2) increasing confidence in the effectiveness and safety of sequestration by identifying and demonstrating cost-effective monitoring technologies, and (3) improving performance-assessment methods to predict and verify that long-term sequestration practices are safe and effective and do not introduce any unintended environmental impacts.

- Decrease the time to implementation by: (1) pursuing early opportunities for pilot tests with our private sector partners, and (2) gaining public acceptance.

On May 17-18, 2000 a project kickoff meeting was held at Lawrence Berkeley National (LBNL) to plan the technical work to be carried out for the FY00 funding allocation. Work was subsequently initiated on four tasks: A) development of sequestration co-optimization methods for EOR, depleted gas reservoirs, and brine formations; B) evaluation and demonstration of monitoring technologies for verification, optimization and safety; C) enhancement and comparison of computer simulation models for predicting, assessing and optimizing geologic sequestration in brine, oil and gas, and coalbed methane formations; and D) improvement of the methodology and information available for capacity assessment of sequestration sites.

Highlights:

- The feasibility of using CO_2 to enhance the recovery of methane from depleted gas reservoirs was assessed in a numerical model study based on the Rio Vista gas field, the largest onshore gas field in California. Results showed that repressurization with CO_2 would result in significant additional amounts of CH_4 being produced for at least 5 years following injection.
- Working with Chevron, baseline studies were performed for a field scale test of monitoring technologies. The work is being carried out in conjunction with a pilot CO_2 flood in the Lost Hills oil field in California. Pre-injection crosswell seismic and crosswell electromagnetic measurements were acquired. A model was built for simulations of seismic and electrical measurements, and laboratory studies were made of the isotopic partitioning of CO_2 in the reservoir rock.
- A first set of test problems was developed for an international intercomparison of reservoir simulators for CO_2 sequestration in oil, gas, brine and coalbed formations.
- A regional sequestration capacity assessment was performed for California, showing that decades of sequestration capacity are available in oil and gas formations. Brine formations have centuries of capacity but further study is needed for optimal site selection.

Papers Published and Presented:

Benson, S.M., An Overview of Geologic Sequestration of CO_2, Presented and published in ENERGEX'2000: Proceedings of the 8^{th} International Energy Forum, pp. 1219-1225, July 23-28, 2000, Las Vegas, NV.

Benson, S.M. and L.R. Myer, The Geo-SEQ Project, presented and published in Proc. Fifth International Conference on Greenhouse Gas Control Technologies, August 13-16, 2000, Cairns, Australia.

Benson, S.M. et al., Carbon Dioxide Reuse and Sequestration: The State of the Art Today, presented and published in Energy 2000: State of the Art, P. Catania (ed.), pp. 205-226, July 23-28, 2000, Las Vegas, NV. (Task D)

Benson, S.M., Comparison of Three Options for Geologic Sequestration of CO_2 – A Case Study for California, presented and published in Proc. Fifth International Conference on Greenhouse Gas Control Technologies, August 13-16, 2000, Cairns, Australia. (Task D)

Hoversten, G.M., and L.R. Myer, Monitoring of CO_2 sequestration using integrated geophysical and reservoir data, presented and published in Proc. of Fifth International Conference on Greenhouse Gas Control Technologies, Cairns, Australia, August 13-16, 2000.

Johnson, J.W., Steefel, C.I., Nitao, J.J. and Knauss, K.G. Reactive transport modeling of subsurface CO_2 sequestration: Identification of optimal target reservoirs and evaluation of performance based on geochemical, hydrologic, and structural constraints presented and published in Proc. of Energex 2000, 8^{th} International Energy Forum, Las Vegas, NV, July 23-28, 2000.

Law, D., Current Numerical Models for Enhanced Coalbed Methane (ECBM) Recovery, presented at The Workshop on Enhanced Coalbed Methane Recovery at Computer Modelling Group, Calgary, Alberta, Canada, June 30, 2000.

Law, D., van der Meer, B., Mavor, M., and Gunter, B., Modelling of Carbon Dioxide Sequestration in Coalbeds: A Numerical Challenge, presented and published in Proc. of The 5^{th} International Conference on Greenhouse Gas Control Technologies (GHGT-5), Cairns, Australia, August 13-16, 2000.

Myer, L.R. and Hoversten, G.M., A strategy for monitoring of geologic sequestration of CO_2,presented and published in Proc. of Energex 2000, 8^{th} International Energy Forum, P Catania, ed., Technomic Publishing, Lancaster PA, pp. 1226-1231,Las Vegas, NV, July 23-28, 2000.

Oldenburg, C.M., K. Pruess, and S.M. Benson, Process modeling of CO_2 injection into natural gas reservoirs for carbon sequestration and enhanced gas recovery, presented and published in Proc. of the 220^{th} National Meeting of the ACS, Vol. 45, No. 4, pp. 726-729, August 20-24, 2000, Washington, D.C., LBNL-45820.

Pruess, K, Tsang, C-F, Law, D. and Gunter, B., Intercomparison of Simulation Models for CO_2 Disposal in Underground Storage Reservoirs, Lawrence Berkeley National Laboratory Report, Berkeley, CA, September 2000.

Outreach Activities:

A website for the GEO-SEQ project has been established at http://esd.lbl.gov/GEOSEQ. The website describes project objectives and the goals of each subtask. Information on the R&D partners and collaborators is provided. Up-to-date information on technical activities and publications is also provided.

Task Summaries

Task A: Develop Sequestration Co-Optimization Methods

Subtask A-1: Co-optimization of carbon sequestration and EOR and EGR from oil reservoirs.

Accomplishments:

- A criteria table for selection of depleted or inactive oil reservoirs for sequestration was drafted.

Summary:
The objectives of this subtask are (1) to assess the feasibility of co-optimization of CO_2 sequestration and EOR and (2) to develop techniques for selecting the optimum gas composition for injection. Results will lay the groundwork necessary for the rapid evaluation of the performance of candidate sequestration sites, as well as monitoring the performance of CO_2 EOR.

Progress this Quarter: The focus of initial work was on assessing the feasibility of CO_2 sequestration in depleted or inactive oil reservoirs and developing selection criteria. A criteria table for selection of depleted reservoirs was drafted. Important reservoir characteristics include depth, degree of formation damage, volume, the volume of oil and water in place, and whether the incremental production is sufficient to warrant bringing an idle field back onto production. A draft report on the topic was begun.

Work Next Quarter: Report on "Criteria for Selecting Oil Reservoirs Suitable for CO_2 Sequestration" will be completed and circulated for comments. Work will begin in the area of developing a technique for choosing the optimum gas composition to maximize sequestration and recovery.

Subtask A-2: Feasibility assessment of carbon sequestration with enhanced gas recovery (CSEGR) in depleted gas reservoirs.

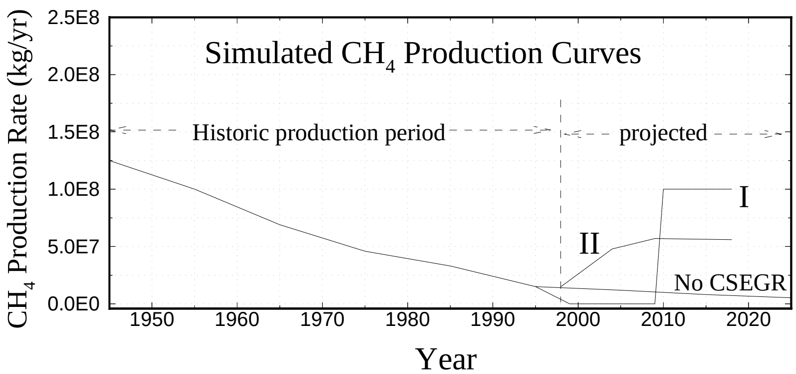
Accomplishments:

- Numerical simulation of the process of CO_2 injection into a model of the Rio Vista Gas Field in California showed that additional methane can be produced from a depleted gas reservoir by injection of CO_2.

Summary:
The objectives of this subtask are to assess the feasibility of injecting CO_2 into depleted natural gas reservoirs for (1) sequestering carbon and (2) enhancing methane (CH_4) recovery. Investigation will include assessments of (1) CO_2 and CH_4 flow and transport processes; (2) injection strategies that retard mixing; (3) novel approaches to inhibit mixing; and (4) identification of candidate sites for a pilot study.

Progress this Quarter: The module EOS7C has been developed for simulating gas and water flow in natural gas reservoirs within the TOUGH2 framework. The module handles five components (water, brine, non-condensible gas, a gas tracer, and methane) along with heat. The non-condensible gas can be selected by the user to be CO_2, N_2, or air. EOS7C is an extension of the EOS7R and EWASG modules. As such, the module is currently restricted to subcritical conditions of gas-like CO_2, i.e., below the critical pressure of 73 bars.

The module has been applied to a model system based on the Rio Vista gas field, the largest onshore gas field in California. At Rio Vista, formerly productive zones have been shut down due to depletion. We simulated historical CH_4 production from a laterally extensive (6.6 km) reservoir, followed by two scenarios (called scenarios I and II) of CSEGR processes. As shown in the figure, significant amounts of additional pure CH_4 can be withdrawn from the reservoir for at least 5 years following CO_2 injection due to repressurization.



Simulated mass production rates of CH_4 for Scenarios I, II, and projected if no CSEGR.

Work Next Quarter: The EOS7C module will be applied to model systems to investigate (1) effects of reservoir heterogeneity and (2) innovative strategies for CO_2 injection. We will also begin to develop a pilot test plan for the Rio Vista gas field.

Subtask A-3: Evaluation of the impact of CO_2 aqueous fluid and reservoir rock interactions on the geologic sequestration of CO_2, with special emphasis on economic implications.

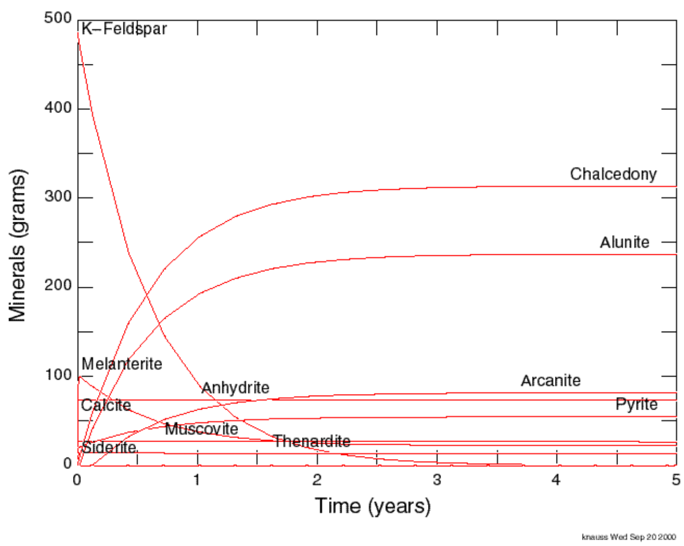
Accomplishments:

- Reaction progress chemical thermodynamic and kinetic simulations were performed for initial evaluation of the impact of SO_2, a waste stream contaminant, on injectivity and sequestration performance.

Summary:
Lowering the costs of the front-end processes can dramatically lower the overall costs of sequestration. One approach is to sequester less-pure CO_2 waste streams that are less expensive or require less energy to separate from flue gas. The objective of this subtask is to evaluate the impacts of this impure CO_2 waste stream on geologic sequestration.

Progress this Quarter: This quarter we focused on the specific impact of SO_2. The approach was to construct a series of simulations with increasing chemical complexity and realism. The simulations started with simple batch-type reactions that simulate titration (and subsequent re-equilibration) of an equilibrated reservoir rock/water system with a gas phase that starts off pure CO_2 and has SO_2 slowly added to it. Various approaches to dealing with mineral or gas buffering of fO_2 (O_2 fugacity) were investigated, as well as systems with or without Fe-bearing mineral phases. We then constructed a series of simulations in which the batch-type reactions are perturbed by periodically flushing out the aqueous phase and permitting the evolved reservoir rock system to re-equilibrate with the “fresh” aqueous phase. This is a “rock-centered”, pseudo-flow-through simulation. Both of these initial types of simulations are pure thermodynamic calculations: no reaction kinetics are invoked. Most recently we have constructed a series of simulations that are equivalent to the first batch-type (closed system) reactions, but this time including dissolution kinetics for all of the mineral phases present in the reservoir rock and assuming a composition and modal abundance appropriate for a feldspathic sandstone containing clay and carbonate with and without an Fe-bearing phase. Again, several approaches to dealing with setting fO_2 were investigated. In these last simulations reaction progress was allowed to proceed for a time period of 30 years, appropriate for a real CO_2 sequestration process.

As an example of the results obtained we show the following plot. In this simulation we have reacted a reservoir rock comprised of 88.5% quartz, 9% K-feldspar, 1% calcite, 1% siderite and 0.5% muscovite (as a proxy for illite) with a gas phase that has fCO_2 = 80 b and enough SO_2 (fSO_2 = 1e-9 b) to drive and keep the pH quite low (pH~0.6) during the entire run. The rock/water ratio is appropriate for a reservoir with 33% porosity and the fluid is a simplified seawater-like brine consisting essentially of 0.7 m NaCl. The reservoir temperature is 60C and full dissolution kinetics are used in rate equations that account for acid catalysis. The run lasts for 30 years, but we have truncated the display to the first 5 years to make the evolving mineral assemblage more clear. We also expanded the Y-scale for the same reason, resulting in the lack of display for the mineral quartz, which increased in abundance by 10.4 g as a result of primarily K-feldspar dissolution. Without going into all the details, the main results are that under these extreme conditions: calcite and K-feldspar react away quickly, siderite is unstable and converts to melanterite and pyrite (a sulfate and a sulfide, respectively), the illite proxy (muscovite) reacts much more slowly, quartz increases in abundance and chalcedony appears owing to K-feldspar and muscovite dissolution, and several other new sulfate phases appear (alunite, arcanite, anhydrite and thenardite).



Work Next Quarter: Investigation of the impact of other contaminants (H_2S, NO_2, etc.) in the CO_2 waste stream will be begun.

Task B: Evaluate and Demonstrate Monitoring Technologies

Subtask B-1: Sensitivity modeling and optimization of geophysical monitoring technologies

Accomplishments:

- Seismic, gravity and electromagnetic modeling for CO_2 injection into a typical depleted gas reservoir was performed in order to test a simulation-based methodology for selection and evaluation of monitoring techniques.
- A model based sensitivity analysis of ERT (electrical resistance tomography) for monitoring CO_2 was carried out.
- Using reservoir simulations provided by Chevron, a geophysical model was built for the Chevron Lost Hills CO_2 injection.

Summary:
The objectives of this task are to: (1) demonstrate methodologies for and carry out an assessment of the effectiveness of candidate geophysical monitoring techniques, (2) provide and demonstrate a methodology for designing an optimum monitoring system, and (3) provide and demonstrate methodologies for interpreting geophysical and reservoir data, in order to obtain high-resolution reservoir images.

Progress this Quarter: Work at LBNL began with a study to test a methodology using reservoir simulation and forward and inverse geophysical modeling to assess the effectiveness of candidate monitoring methods. The methodology was demonstrated using numerical models representing typical hydrocarbon reservoirs that might be candidates for CO_2 sequestration. Results for a case in which a fault provided a leakage path showed that combined gravity, seismic and crosswell EM geophysics could be used to detect such a feature.

LBNL worked with Chevron to assemble all the petrophysical analysis, well log data, geophysical data and reservoir simulations for the Lost Hills CO_2 pilot project. Code was written to translate the Chevron reservoir simulation model into the LBNL 'GEM' (geophysical earth modeling) package. Multi-regressions have been run on all wells in the pilot area to determine Archie's law constants for electrical resistivity prediction. Work has begun on determining an appropriate model relating velocity and density to porosity, Sw, Sg and pressure in the pilot area. An initial finite-difference model for the pre-CO_2 injection case has been built and testing of the electromagnetic and seismic numerical codes on this model has begun.

In a companion study, LLNL preformed a model based sensitivity analysis for the ERT (electrical resistance tomography) method during a simulated CO_2 flood. The study addresses different scales of CO_2 movement. CO_2 flow in isolated fractures as well as within uniform layered units is addressed.

Work Next Quarter: Results of reservoir simulation runs provided by Chevron for CO_2 injection will be converted to electrical resistivity and velocity and used to compute the expected geophysical responses. The computed responses will be compared to the observed data and used to update both the geologic and petrophysical models in order to improve the fit between observed and calculated data. Electromagnetic (EM) 3D inversions will be preformed on the time-lapse EM data to produce images of electrical conductivity as well as time lapse changes in electrical conductivity. These will be used to predict CO_2 movement within the reservoir. The EM images will be compared with seismic tomographic images, if differences are found the inversion process will be iterated to attempt to reconcile the velocity and conductivity images.

<u>Subtask B-2</u>: Field data acquisition for CO_2 monitoring using geophysical methods

Accomplishments:

- Baseline (pre-injection) crosswell seismic measurements were completed at Chevron Lost Hills CO_2 injection test site. Chevron completed crosswell electromagnetic measurements at the same location.

Summary:

The goal of this subtask is to demonstrate through field testing the applicability of single-well, crosswell, and surface-to-borehole seismic, and crosswell electromagnetic (EM) and electrical resistance tomography (ERT) methods for subsurface imaging of CO_2.

<u>Progress this Quarter</u>: A suite of borehole seismic experiments were carried out at the Chevron CO_2 injection pilot site between August 1 and August 11, 2000. Two observation wells, OB-C1 and OB-C2, were used for seismic crosswell and single well acquisition. The observation wells are about 25 and 88 feet, respectively, from the CO_2 injection well, 11-8WR. These seismic surveys will be the baseline data set representing in-situ properties prior to CO_2 injection.

The seismic acquisition featured use of a high frequency (about 1 - 5 kHz) piezoelectric source, and a low frequency (about 50 - 400 Hz) P- and S-wave orbital vibrator source. Three-component clamping accelerometer sensors were used for both surveys to provide optimal measurement of high frequencies and shear-wave ground motion. The range of frequencies spanned by the two surveys allows monitoring of physical processes with a wide range of spatial sampling.

The surveys covered the following depths:

Crosswell:
Piezoelectric source: 2130 - 1465 @ 5 foot intervals
Orbital Vibrator source: 2130 - 1300 @ 10 foot intervals

Singlewell:
Hydrophone sensors: 2020 - 1500 @ 2 foot intervals
3-component sensors: 1850 - 1550 @ 5 foot intervals

Initial analysis of the piezoelectric data shows a clear separation of high frequencies (about 2200 Hz) body waves and later arriving low frequency (about 400 Hz) waves which are presumably tube-waves generated in the receiver well. First arrivals shows velocities of about 5800 ft/s, which is comparable with previously measured P-wave velocities in diatomite. A large change in crosswell amplitudes and travel times at 2040 feet, just at the bottom of the hydrofractured interval was also observed.

Complementing the cross well seismic survey, an electromagnetic (EM) cross well survey was carried out by Chevron and transferred to LBNL for processing.

<u>Work Next Quarter</u>: Processing of the cross well seismic and EM data sets will be initiated. Preparations will be made for the post-injection, time-lapse surveys.

Subtask B-3: Application of natural and introduced tracers for optimizing value-added sequestration technologies

Accomplishments:

- Laboratory measurements of the fractionation of CO_2 in reservoir rock from the Chevron Lost Hills test site were performed.

Summary:

The overall goal of this effort is to provide methods which utilize the power of natural and introduced tracers to decipher the fate and transport of CO_2 injected into the subsurface. The resulting data will be used to calibrate and validate predictive models used for (1) estimating CO_2 residence time, reservoir storage capacity, and storage mechanisms; (2) testing injection scenarios for process optimization; and (3) assessing the potential leakage of CO_2 from the reservoir.

Progress this Quarter: In order to use the stable isotope compositions of carbon and oxygen in CO_2 as effective tracers during the injection tests we need to understand how these isotopes partition as a consequence of different process pathways (e.g., mineral reactions; sorption; aqueous dissolution). We investigated one important isotopic partitioning pathway, that of CO_2 interacting with hydrocarbon-saturated rock (an EOR injection scenario) in static mode. We obtained hydrocarbon-bearing core from Chevron's Lost Hills field (well OB-7). Four samples were selected for study: two taken in an horizontal orientation (sandy diatomites -H-1450.8 and H-1460.7) and two with a vertical orientation (diatomites:V-1685.8 and V-1706.0). Approximately 1.5 gms from each core were disaggregated, loaded into a two zone reaction vessel and reacted with a small quantity (2.33E-5 moles, ~0.001gms) of dry CO_2 (initial $\delta^{13}C_{PDB}$ = 50.4% and $\delta^{18}O_{PDB}$ = -13.47%). CO_2 was also loaded into a fifth vessel (control) containing no core sample to measure possible partitioning between CO_2 and the vessel walls. These systems were allowed to react for 72 hours at 25°C. A small aliquot of CO_2 was isolated from the solid in the upper portion of each vessel and analyzed isotopically. The CO_2 from the control vessel showed no isotopic variation from the starting composition. Without exception, the CO_2 sampled in the presence of the solid was isotopically enriched in both carbon and oxygen relative to CO_2 lost to the solid (sorption?). CO_2 reacted with sandy diatomites (horizontal orientation) was heavier in $\delta^{13}C$ by between 3.5 and 4% relative to "fixed" CO_2, whereas enrichments of between 6.3 and nearly 7% were observed for CO_2 reacted with diatomite. The $\delta^{18}O$ enrichments in CO_2 relative to "fixed" CO_2 were similar in magnitude regardless of lithology – roughly 17 to 20%. The magnitude of the carbon isotope partitioning is comparable to what others have observed for CO_2 interaction with aqueous solutions. The preliminary conclusion to draw here is that a light isotopic component of CO_2 may be retained in the reservoir leading to progressively heavier isotopic CO_2 farther down the flow path. Clearly, more effort is needed to quantify how these isotopes fractionate as a function of temperature, PCO_2, surface area, hydrocarbon composition, mineral composition, solid to volatile mass ratios, presence of H_2O, and ultimately, flow rate.

In parallel, we have been evaluating a suite of tracers to add to the CO_2 injection stream that will allow us to both track migration of the injected gas over time as well as to provide us with surrogates that can be used to estimate partitioning of CO_2 during transport through the mechanisms being investigated by the stable isotope experiments listed above. We will select a nonreactive tracer as well as one or more reactive tracers targeting selected processes (e.g., sorption or partitioning into hydrocarbons). These tracers will be evaluated under the same conditions and using the same reservoir materials as the CO_2 in order to develop the relationships that will allow the tracers to serve as "surrogates" for CO_2 transport in the subsurface.

Work Next Quarter: Efforts in the next quarter will focus on two main areas: (a) completion of the design of flow-through column tracer apparatus and its initial testing using a select group of rock types and gas tracers and (b) continuation of core-gas-fluid isotope exchange experiments, emphasizing initially the Lost Hill samples, but then expanding to somewhat more generic materials common to saline aquifers (e.g., mudstones, limestones, sandstones). Ideally, when a field test site is selected we will want to run these column experiments using core material and fluids obtained from that site. However, we can use the available core for initial experiments, which will allow us to evaluate CO_2-fluid-rock interactions as well as the parallel reactive tracer interactions.

Of the tracers available, coupled use of SF_6 and selected perfluorocarbons holds good promise for this application, in part because they've been used in previous deep subsurface applications and so their behavior is documented under some environmental conditions. The gases could be analyzed all in one run by instrumenting a GC with two columns in series (they require separate different column types), which has been done before and documented in the literature. It's possible even to set up online analysis in the field, which would be important for using a periodic input signal. The other benefits to using these gases are an extremely low detection limit (less than ppb), their relative inertness, and low (to none) background concentrations. The latter is an advantage over some of the noble gases such as He and Ar, where natural background levels could be significant thereby lowering the effective detection limit.

Task C: Enhance and Compare Simulation Models

Subtask C-1: Enhancement of numerical simulators for greenhouse gas sequestration in deep, unminable coal seams.

Accomplishments:

- A workshop on Enhanced Coalbed Methane Recovery (ECBM) was organized with experts in the areas of numerical simulation, field operations and physical processes to identify the important mechanisms necessary for the numerical simulation of CO_2 sequestration in deep, unminable coalbed seams.

Summary:
The goal of this subtask is to improve simulation models for capacity and performance assessment of CO_2 sequestration in deep, unminable coal seams.

Progress this Quarter: A workshop on Enhanced Coalbed Methane Recovery (ECBM) was held at Computer Modelling Group (CMG), Calgary, Alberta, Canada on June 30, 2000 with experts in the areas of numerical simulation, field operation and academic. A list of the important mechanisms necessary for the numerical simulation of CO_2 sequestration in deep, unminable coalbed seams such as: (1) mixed gas adsorption, (2) mixed gas diffusion between coal cleats and matrix, (3) coal swelling and shrinkage, and (4) non-isothermal effect, were identified. Discussions in the workshop were focused on the capability of the existing numerical simulators and the identification of area of improvement.

Two preliminary sets of relatively simple numerical simulation problems have been setup to compare CBM numerical simulators taking into account the existing simulation capabilities of these simulators. The first problem set is a single well test with CO_2 injection into a coal seam and the second problem set is an ECBM process with CO_2 injection in a 5-spot well pattern. At this stage, instantaneous gas diffusion between coal cleats and matrix was assumed, such that CBM simulators with single porosity model only can also be evaluated. These test problems have been incorporated into the code comparison activities in Subtask C-2.

Testing of the problem sets using CMG's simulators STARS and GEM is ongoing.

Work Next Quarter: Testing of the preliminary problem sets using CMG's STARS and GEM will be completed. The selection of the first set of benchmark problems will be finalized.

An ARC website to document problem sets and post solutions and discussions will be established. More complex problem sets in which several important mechanisms such as mixed gas diffusion (using dual porosity model) and coal shrinkage/swelling will be developed.

Subtask C-2: Intercomparison of reservoir simulation models for oil, gas, and brine formations

Accomplishments:

- An approach and a first set of test problems was developed for an international intercomparison study of codes for CO_2 sequestration in oil, gas, brine and unminable coal formations.

Summary:
The objective of this subtask is to stimulate the development of models for predicting, optimizing, and verifying CO_2 sequestration in oil, gas, and brine formations. The approach involves: (1) developing a set of benchmark problems, (2) holding workshops of industrial, academic, and laboratory researchers (3) soliciting and obtaining solutions for these problems, and (4) publishing results.

Progress this Quarter: We have developed a systematic approach for an intercomparison study of numerical simulation models for CO_2 sequestration. This was written up as a laboratory report which includes specifications of a first set of test problems (see Table 1).

Table 1. First set of test problems for code intercomparison study.

process	problem title
carbon sequestration with enhanced gas recovery	1. Mixing of stably stratified CO_2-CH_4 gases by diffusion with gravity effects 2. Advective-diffusive mixing of CO_2-CH_4 due to lateral density gradient
aquifer disposal of CO_2	3. Radial flow from a CO_2 injection well 4. CO_2 discharge along a fault zone
hydro-mechanical coupled processes	5. Caprock deformation, uplift, and permeability change during CO_2 injection in an aquifer
CO2 sequestration in coalbeds	6. Single well CO_2 injection test 7. 5-spot CO_2 injection process

Work Next Quarter: The report mentioned above will be distributed to interested groups worldwide to solicit their input and participation in the intercomparison study. A website will be established to share information and coordinate the study. Simulations of the first test problem set will be initiated. Additional test problems will be developed.

Task D: Improve the Methodology and Information for Capacity Assessment

Accomplishments:

- A preliminary evaluation was completed of the sequestration potential of oil, gas and brine formations within California.

Summary:

The objectives of this task are to: (1) improve the methodology and information available for assessing the capacity of oil, gas, brine, and unminable coal formations and (2) provide realistic and quantitative data for construction of computer simulations that will provide more reliable sequestration capacity estimates.

Progress this Quarter: The GEO-SEQ project plans to use realistic data sets generated by the Texas Bureau of Economic Geology (TBEG) to perform simulations of sequestration capacity in brine formations. As part of another NETL sponsored project, the TBEG team has now completed a large digital map data base containing basic quantitative data on injectivity and seal properties in 21 prospective target basins onshore US. Based on sequestration potential and proximity to CO_2 sources, we have selected the Frio/Oakville formations for first detailed simulations.

During this quarter, we also performed a regional sequestration capacity assessment for California. The study provided a preliminary evaluation of the sequestration potential of oil, gas and brine formations within the state and compared potential sites with the location of large CO_2 sources from fossil fuel fired power plants. The conclusion of this study is that decades of sequestration capacity are available in oil formations and that significant new capacity is being added at today's productions rates. Gas formations provide less capacity, but where they are located in close proximity to a power plant, can provide decades of capacity from individual plants. Brine formations have centuries of capacity but additional studies will be needed to select the optimal sites. Opportunities for EOR and EGR exist and should be explored.

Work Next Quarter: We will collect data and prepare an annotated bibliography on Frio/Oakville prospective storage targets at a reservoir scale in the Houston-Bay city area. We will then begin simulations to identify critical issues related to sequestration capacity in the Frio/Oakville formations. In addition, we are compiling information on underground injection control (UIC), injection of class I hazardous wastes into the deep subsurface, to provide context for understanding regulatory and monitoring needs for underground injection in the state of Texas.